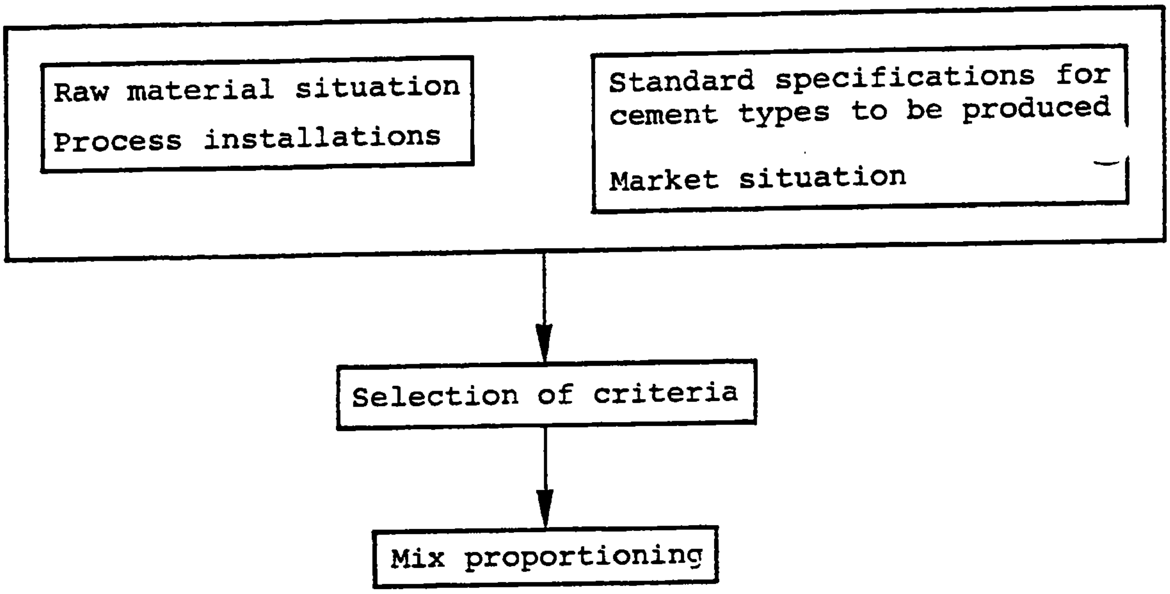
# MIX DESIGN

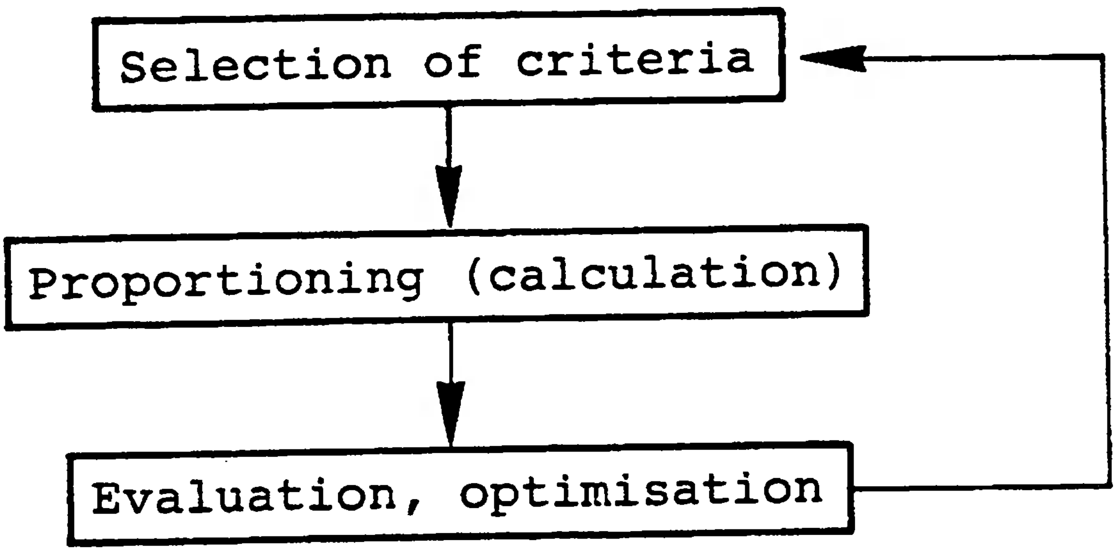
## 1. GENERAL

A raw mix design comprises not only raw mix proportioning but also considerations of such factors as standard specifications of the cement types to be produced, the market situation and the available process installations.




The selection of criteria is dictated by the standard specifications.

Designing raw mixes does not only involve the proportioning (calculation) but includes an evaluation of the obtained results. The latter involves optimisation with respect to costs and materials.

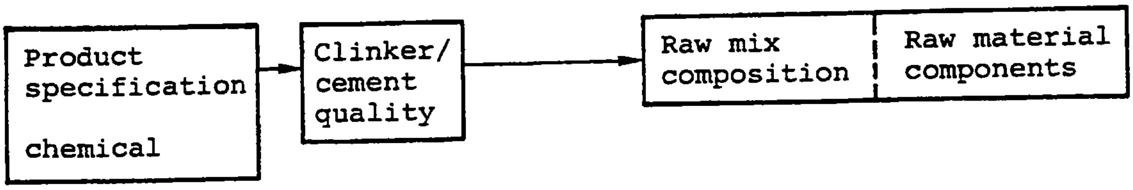


## 2. DEFINITION OF CRITERIA FOR MIX CALCULATION

Any type of cement has to conform to the individual cement standards of a particular country. Standards (standard specifications) normally include chemical specifications for clinker and cement. Together with the physical and strength requirements, they guarantee a suitable quality potential for the respective cement type.

With regard to the raw material aspects only the chemical requirements are significant:




In other words: the product specifications dictate the clinker/cement quality which in turn dictates the chemical composition of the raw mix and finally the selection of the raw material components.

The above sequence can also be reversed: an existing raw material configuration with little freedom as to the proportioning of the raw mix, may permit the manufacture of only one particular type of clinker.

**Table 41 Influence of chemical requirements on raw materials**

| Chemical requirements | Influence on raw material |
|---|---|
| min. $SO_3$ | Rejection of $SO_3$-bearing components (e.g.) gypsum-containing shale) |
| min. MgO | Rejection of MgO-bearing components (e.g. dolomitic limestone) |
| min. Alkali | Selection of raw material with low alkali-content |
| min. $C_3A$ | Selection of components with very low alumina content and / or high iron content |

Table 41 shows the influence of chemical requirements on the choice of raw materials.

The following chemical criteria are normally used as a basis for raw mix proportioning (Table 42; on clinker basis):

**Table 42 Chemical criteria for raw mix proportioning**

| criteria | "normal" range limit (for clinker) | formulas, remarks |
|---|---|---|
| MgO | max. 5% (6%) | for all cements |
| $SO_3$* | 3 - 4,5% | depending on cement type |
| LIME STANDARD or LIME SATURATION FACTOR | 0,9 - 1. or 90 - 100% | $\frac{CaO}{2,8\ SiO_2 + 1,2\ Al_2O_3 + 0,65\ Fe_2O_3}$ |
| "Improved" Lime standard ** | 90 - 100% | $\frac{100\ (CaO + 0,75\ MgO)\ **}{2,80\ SiO_2 + 1,18\ Al_2O_3 + 0,65\ Fe_2O_3}$ |
| Index of activity | 2,5 - 3,5 | $\frac{SiO_2}{Al_2O_3}$ |
| Hydraulic ratio | 2,0 - 2,4 | $\frac{CaO}{SiO_2 + Al_2O_3 + Fe_2O_3}$ |
| SILICA RATIO | 1,8 - 3,4 | $\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$ |
| ALUMINA RATIO | 1,5 - 2,5 (0,7 - 3,5) | $\frac{Al_2O_3}{Fe_2O_3}$ |
| Total alkali | < 0,6% | $Na_2O$ + 0,66 $K_2O$ for low alkali clinker |
| $C_3S$ | 50 - 60% | except for ASTM type IV |
| $C_3A$ | max. 3% BS max. 5% ASTM | for sulfate-resisting cement |

* for cement ** 100 (CaO + 1,5) for MgO < 2%

The proportioning of raw mixes for ordinary Portland cement is mostly based on the following specific criteria:

- MgO
- Lime standard or lime or saturation factor (or $C_3S$)
- Silica ratio
- Alumina ratio

As Table 42 indicates, ratios are the preferred chemical criteria for proportioning since they offer the advantage of expressing the main and most important chemical parameters such as $SiO_2$, $Al_2O_3$, $Fe_2O_3$ and CaO in one single figure.

Other important criteria such as type and composition of fuels should not be overlooked. Coal ash as a combustion product of coal, for instance, has to be analysed quantitatively and qualitatively and should be treated as an individual raw material component. Fuel oil has to be considered as a potential carrier of sulphur, etc.

Additional criteria which could have bearing on the mix proportioning refer to performance characteristics, e.g.:

- minimum dust emission
- burnability and coating properties
- extreme components which affect machine performance

or to economic factors, e.g.:

- maximum overall economy
- easy and simple operations
- minimum number of components

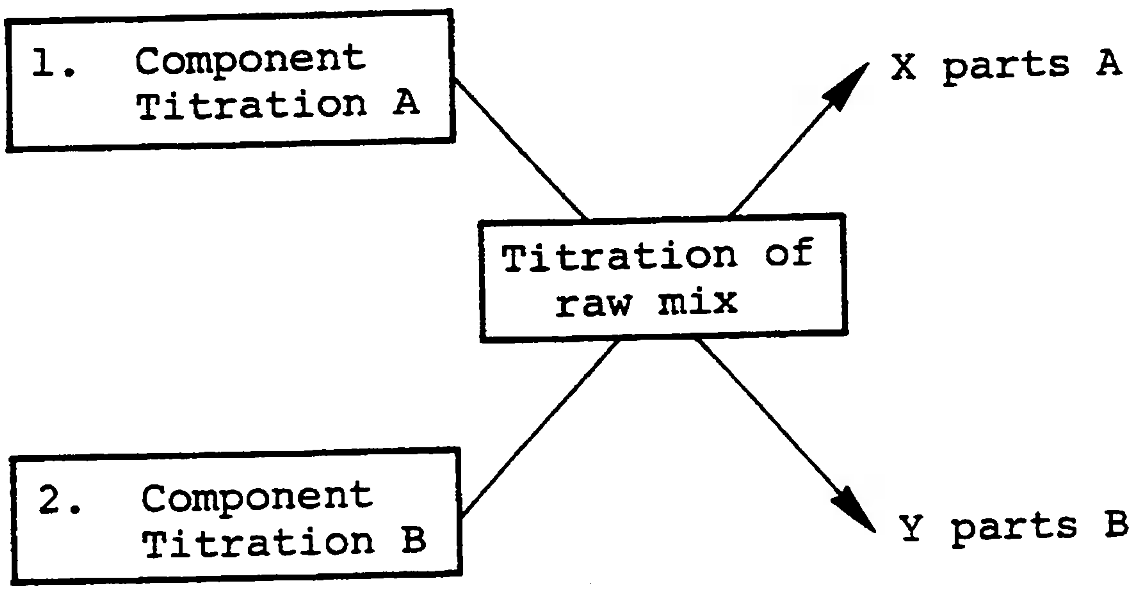
However, performance characteristics in particular can normally be controlled regarding the "normal" chemical requirements for cement raw mixes. The economic factors, on the other hand, are of the same significance as the chemical requirements.

## 3. PRINCIPLES AND METHODS OF MIX PROPORTIONING

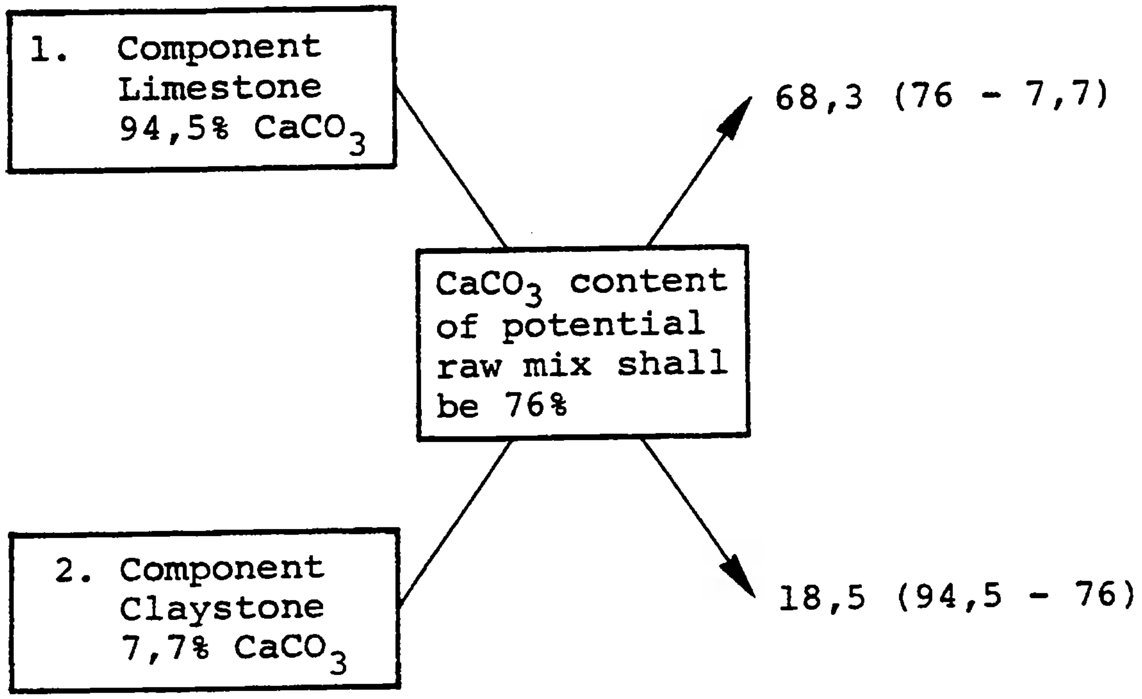
Proportioning (calculation) of potential cement raw mixes can be accomplished by various methods:

### 3.1 X-Pattern

The x-pattern represents a linear estimation of two raw material components by selecting the anticipated titration value (total carbonate content) of the potential raw mix as basis.




or as a numerical example.




The potential raw mix with a titration value of 76% would thus consist of:

$$\frac{\text{limestone}}{\text{claystone}} = \frac{68.3}{18.5} = \frac{3.69}{1}$$

or

| |
|---|
| limestone 78,6 %<br>claystone 21,3 % |

The resulting analysis of the raw mix has to be checked with regard to the requirements of the standard specifications.

### 3.2 Manual Calculation

There are a number of mathematical methods for two and three-component systems. Formulas are not complicated but comprise a large number of steps. The method of manual calculation as such is outdated.

### 3.3 Graphical Methods

These methods require preparatory work (manual calculations) for the determination of the relevant figures which are the basis for the construction of the diagrams and graphs. Graphical methods represent a rather archaic stage of mix proportioning.

### 3.4 Programmable Calculator

Programmable calculators normally produce one solution (out of possibly several). Obviously, this method is the best way to obtain a quick solution.

### 3.5 Computer Optimisation

It provides the optimum of a series of possible solutions considering the price factors as variables. If the available raw materials cannot meet the specified requirements for the raw

mix, an approximate and an exact solution considering the missing constituents are produced (Tables 43 - 47).

Note: Mix calculations are normally based on dry raw materials. In practice, the natural moisture contents of the raw material components have to be considered too. This may entail alterations of the original mix proportions.

**Table 43**

15742222 GLADSTONE

ANALYSEN

| KOMPONENTEN | GVER | SIO2 | AL2O3 | FE2O3 | CAO | MGO | K2O | NA2O | REST | CAOFREI | SO3 | PREIS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CALLIDE COAL | 0 | 46.17 | 37.81 | 11.34 | 1.00 | 1.55 | .40 | .35 | .58 | 0 | 0 | 1.00E 06 |
| LIME 7734 | 43.29 | 1.40 | .45 | .29 | 54.09 | .49 | .02 | .02 | .35 | 0 | 0 | 1.00E 00 |
| OVBURD 7733 | 13.92 | 48.30 | 17.50 | 12.20 | 4.10 | .59 | .14 | .50 | 2.73 | 0 | 0 | 1.00E 00 |
| SAND | .71 | 94.80 | 2.88 | .24 | .35 | .13 | 1.79 | .20 | 0 | 0 | 0 | 1.00E 03 |
| CINDERS | 1.43 | 25.50 | 3.30 | 66.70 | 1.20 | 1.44 | .24 | .17 | .08 | 0 | 0 | 1.00E 04 |

ANFORDERUNGEN

| | OBERE GRENZE | UNT. GRENZE | RESULTAT |
|---|---|---|---|
| MGO | 100.000 | | .812 |
| NA2O+0.658K2O | 100.000 | | .283 |
| AL2O3 | 100.000 | | 5.804 |
| FE2O3 | 100.000 | | 4.050 |
| SIO2 | | 0 | 21.794 |
| KALKSTANDARD | 1000.550 | -0.050 | 92.353 |
| TONERDE-MODUL | 100.325 | -0.025 | 1.170 |
| SILIKAT-MODUL | 2.025 | 1.975 | 2.025 |
| C3S | 55.530 | 54.500 | 55.500 |
| C2S | | -100.000 | 20.439 |
| C3A | 7.200 | | 7.080 |
| C4AF+2C3A | 200.500 | | 29.074 |
| KOMPONENTE 1 | .025 | .024 | |

RESULTATE

| MISCHUNGSVERHAELTNIS | |
|---|---|
| CALLIDE COAL | .0245 |
| LIME 7734 | .7743 |
| OVBURD 7733 | .1292 |
| SAND | .0553 |
| CINDERS | .0167 |
| TOTAL | 1.0000 |

| KLINKER-ANALYSE | |
|---|---|
| C3S | 55.5040 |
| C2S | 20.6391 |
| C3A | 7.0090 |
| C4AF | 15.0740 |
| MGO | .8121 |
| ALKALI | .3449 |
| CAOFREI | 0 |
| TONERDEMODUL | 1.1705 |
| SILIKATMODUL | 2.0240 |
| KALKSTANDARD | 92.3526 |
| SIO2 | 21.7937 |
| AL2O3 | 5.8036 |
| FE2O3 | 4.9586 |
| CAO | 65.6571 |
| MGO | .8121 |
| K2O | .1803 |
| NA2O | .1586 |
| HYDR. MODUL | 2.0147 |
| GIPS | 0 |
| PREIS | 2.23001E 02 |

## Table 44

2064 05050-044 MIXES ILIGAN NR 4      28. 6. 77 OPTIMIERUNG

A N A L Y S E N

| NR | GVER | SIO2 | AL2O3 | FE2O3 | CAO | MGO | K2O | NA2O | TIO | CRO | MNO | SO3 | P2O | CL | F | REST | PREIS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4290 | 190 | 68 | 39 | 5290 | 42 | 4 | 4 | 3 | 0 | 8 | 8 | 4 | 1 | 0 | 45 | .10+00 |
| 2 | 1925 | 4150 | 1207 | 598 | 1576 | -239 | 99 | 109 | 52 | 0 | 8 | 9 | 11 | 9 | 0 | 0 | .10+00 |
| 3 | 839 | 6380 | 1329 | 400 | 340 | 92 | 219 | 250 | 44 | 0 | 6 | 9 | 8 | 11 | 0 | 68 | .22+00 |
| 4 | 293 | 1477 | 297 | 7297 | 247 | 53 | 40 | 31 | 55 | 0 | 2 | 141 | 0 | 0 | 0 | 65 | .59+00 |

A N F O R D E R U N G E N      R E S U L T A T E

| | MAX. | MIN. | RRESULTAT | MISCHUNGSVERHAELTNIS | | KLINKERANALYSE | |
|---|---|---|---|---|---|---|---|
| MGO | 100.000 | .000 | 1.145 | LIMESTONE | .7535 | C3S | 59.5000 |
| NA2O+.658K2O | 100.000 | .000 | 1.143 | SHALE LOW | .1262 | C2S | 17.8631 |
| AL2O3 | 100.000 | .000 | 5.575 | SHALE HIGH | .1145 | C3A | 9.6675 |
| FE2O3 | 100.000 | .000 | 3.022 | PYRITE CIND | .0059 | C4AF | 9.1863 |
| SIO2 | 100.000 | .000 | 21.880 | | .0000 | MGO | 1.1453 |
| KALKSTANDARD | 1000.050 | -.050 | 94.179 | | .0000 | ALKALI | 1.3610 |
| TONERDEMODUL | 1.845 | 1.795 | 1.845 | | .0000 | HYDR. MODUL | 2.1371 |
| SILIKATMODUL | 2.595 | 2.545 | 2.545 | | .0000 | TONERDEMODUL | 1.8450 |
| C3S | 60.500 | 59.500 | 59.500 | | .0000 | SILIKATMODUL | 2.5450 |
| C2S | 100.000 | -100.000 | 17.865 | | .0000 | KALKSTANDARD | 94.1791 |
| C3A | 100.000 | .000 | 9.668 | | .0000 | SIO2 | 21.8795 |
| C4AF+2C3A | 200.000 | -100.000 | 28.521 | ****************** | | AL2O3 | 5.5753 |
| KOMPON. 1 | 1.000 | .000 | .753 | T O T A L | 1.0000 | FE2O3 | 3.0218 |
| | | | | | | CAO | 65.7423 |
| | | | | | | MGO | 1.1453 |
| OPTIMUM | | | | PREIS | .11874+00 | K2O | .6395 |
| | | | | | | NA2O | .7225 |
| | | | | | | TIO2 | .2242 |
| | | | | | | CR2O3 | .0000 |
| | | | | | | MN2O3 | .1224 |
| | | | | | | SO3 | .1441 |
| | | | | | | P2O5 | .0864 |
| | | | | | | CL | .0509 |
| | | | | | | F | .0000 |
| | | | | | | REST | .6582 |

## Table 45

OPTIMALISIERUNG

9052 05850,044 MIXES ILIGAN NO. 1

ANALYSEN

| KOMPONENTEN | GVER | SIO2 | AL2O3 | FE2O3 | CAO | MGO | K2O | NA2O | REST | CAOFREI | SO3 | PREIS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LIMESTONE | 47,90 | 1,90 | ,69 | ,40 | 52,90 | ,43 | ,04 | ,05 | ,69 | 0 | 0 | 1,40E 01 |
| SHALE LOW | 19,30 | 41,60 | 12,10 | 6,00 | 15,00 | 2,40 | 1,00 | 1,10 | ,70 | 0 | 0 | 1,40E 01 |
| SHALE HIGH | 8,40 | 63,80 | 13,30 | 4,00 | 3,40 | ,93 | 2,20 | 2,50 | 1,47 | 0 | 0 | 2,10E 01 |
| PYRITE CIND | 2,96 | 14,90 | 2,90 | 73,60 | 2,50 | ,59 | ,41 | ,32 | 1,02 | 0 | 0 | 5,41E 01 |
| SILICA SAND | 3,50 | 89,30 | 2,50 | 2,10 | 1,00 | ,28 | ,02 | ,00 | ,42 | 0 | 0 | 5,05E 01 |

ANFORDERUNGEN

| | OBERE GRENZE | UNT. GRENZE | RESULTAT |
|---|---|---|---|
| MGO | 100.000 | | 1.251 |
| NA2O+0,658K2O | 103.000 | | .432 |
| AL2O3 | 105.000 | | 4.666 |
| FE2O3 | 105.000 | | 3.009 |
| SIO2 | | 0 | 21.021 |
| KALKSTANDARD | 1000.050 | -1.050 | 96.437 |
| TONERDE-MODUL | 1.225 | 1.175 | 1.225 |
| SILIKAT-MODUL | 2.475 | 2.575 | 2.575 |
| C3S | 68.500 | 67.500 | 68.500 |
| C2S | | -100.000 | 10.909 |
| C3A | 100.000 | | 5.927 |
| C4AF+2C3A | 200.000 | | 23.433 |
| KOMPONENTE 1 | 1.000 | 0 | |

RESULTATE

MISCHUNGSVERHAELTNIS

| | |
|---|---|
| LIMESTONE | ,7472 |
| SHALE LOW | ,1912 |
| SHALE HIGH | 0 |
| PYRITE CIND | ,0121 |
| SILICA SAND | ,0495 |
| TOTAL | 1,0000 |

KLINKER-ANALYSE

| | |
|---|---|
| C3S | 68,5098 |
| C2S | 10,9092 |
| C3A | 5,9272 |
| C4AF | 11,5743 |
| MGO | 1,2510 |
| ALKALI | ,7533 |
| CAOFREI | 0 |
| TONERDEMODUL | 1,2250 |
| SILIKATMODUL | 2,5750 |
| KALKSTANDARD | 96,4373 |
| SIO2 | 21,0212 |
| AL2O3 | 4,6656 |
| FE2O3 | 3,0097 |
| CAO | 66,6193 |
| MGO | 1,2510 |
| K2O | ,3545 |
| NA2O | ,3090 |
| HYDR. MODUL | 2,1990 |
| GIPS | 0 |
| PREIS | 1,25620E 01 |

## Table 46

OPTIMALISIERUNG

2057 05050,044 MIXES ILIGAN NO. 7

**ANALYSEN**

| KOMPONENTEN | OVER | SIO2 | AL2O3 | FE2O3 | CAO | MGO | K2O | NA2O | REST | CAOFREI | SO3 | PREIS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LIMESTONE | 42,90 | 1,90 | ,69 | ,40 | 52,90 | ,43 | ,04 | ,05 | ,69 | 0 | 0 | 1,00E 01 |
| SHALE LOW | 19,33 | 41,60 | 12,10 | 6,00 | 15,00 | 2,40 | 1,00 | 1,10 | ,78 | 0 | 0 | 1,00E 01 |
| SHALE HIGH | 8,40 | 63,80 | 13,30 | 4,00 | 3,40 | ,93 | 2,20 | 2,50 | 1,47 | 0 | 0 | 2,10E 01 |
| PYRITE CIND | 2,96 | 14,90 | 2,90 | 73,60 | 2,50 | ,59 | ,41 | ,32 | 1,02 | 0 | 0 | 5,01E 01 |
| SILICA SAND | 3,50 | 89,30 | 2,50 | 2,10 | 1,60 | ,28 | ,02 | ,00 | ,42 | 0 | 0 | 5,05E 01 |

**ANFORDERUNGEN**

| | OBERE GRENZE | UNT. GRENZE | RESULTAT |
|---|---|---|---|
| MGO | 100.000 | | 1.488 |
| NA2O+0,658K2O | 100.000 | | .821 |
| AL2O3 | 100.000 | | 5.874 |
| FE2O3 | 100.000 | | 3.718 |
| SIO2 | | 0 | 21.593 |
| KALKSTANDARD | 1000.050 | -0.050 | 94.654 |
| TONERDE-MODUL | 1.825 | 1.775 | 1.825 |
| SILIKAT-MODUL | 2.425 | 2.375 | 2.375 |
| C3S | 60.500 | 59.500 | 59.500 |
| C2S | | -100.000 | 17.045 |
| C3A | 100.000 | | 10.120 |
| C4AF-2C3A | 200.000 | | 30.036 |
| KOMPONENTE 1 | 1.000 | 0 | |

**RESULTATE**

| MISCHUNGSVERHAELTNIS | |
|---|---|
| LIMESTONE | ,7163 |
| SHALE LOW | ,2665 |
| SHALE HIGH | 0 |
| PYRITE CIND | ,0020 |
| SILICA SAND | ,0152 |
| TOTAL | 1,0000 |

| KLINKER-ANALYSE | |
|---|---|
| C3S | 59,5000 |
| C2S | 17,0454 |
| C3A | 10,1259 |
| C4AF | 9,7839 |
| MGO | 1,4877 |
| ALKALI | ,9789 |
| CAOFREI | 0 |
| TONERDEMODUL | 1,8250 |
| SILIKATMODUL | 2,3750 |
| KALKSTANDARD | 94,6540 |
| SIO2 | 21,5934 |
| AL2O3 | 5,8736 |
| FE2O3 | 3,2184 |
| CAO | 65,7698 |
| MGO | 1,4877 |
| K2O | ,4625 |
| NA2O | ,5164 |
| HYDR. MODUL | 2,1434 |
| GIPS | 0 |

"HOLDERBANK"

Table 47

2066 05050-044 MIXES ILIGAN NR 11    28. 6. 77 OPTIMIERUNG

A N A L Y S E N

| NR | GVER | SIO2 | AL2O3 | FE2O3 | CAO | MGO | K2O | NA2O | TIO | CRO | MNO | SO3 | P2O | CL | F | REST | PREIS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4290 | 190 | 68 | 39 | 5290 | 42 | 4 | 4 | 3 | 0 | 8 | 8 | 4 | 1 | 0 | 45 | .10+00 |
| 2 | 1925 | 4150 | 1207 | 598 | 1576 | 239 | 99 | 109 | 52 | 0 | 8 | 9 | 11 | 9 | 0 | 0 | .10+00 |
| 3 | 839 | 6380 | 1329 | 400 | 340 | 92 | 219 | 250 | 44 | 0 | 6 | 9 | 8 | 11 | 0 | 68 | .22+00 |
| 4 | 293 | 1477 | 287 | 7297 | 247 | 53 | 40 | 31 | 55 | 0 | 2 | 141 | 0 | 0 | 0 | 65 | .58+00 |

A N F O R D E R U N G E N    R E S U L T A T E

| | MAX. | MIN. | RRESULTAT | MISCHUNGSVERHAELTNIS | | KLINKERANALYSE | |
|---|---|---|---|---|---|---|---|
| MGO | 100.000 | .000 | 1.362 | LIMESTONE | .7290 | C3S | 59.5000 |
| NA2O+.658K2O | 100.000 | .000 | 1.010 | SHALE LOW | .2116 | C2S | 16.6421 |
| AL2O3 | 100.000 | .000 | 5.933 | SHALE HIGH | .0555 | C3A | 10.2874 |
| FE2O3 | 100.000 | .000 | 3.216 | PYRITE CIND | .0039 | C4AF | 9.7754 |
| SIO2 | 100.000 | .000 | 21.453 | | .0000 | MGO | 1.3622 |
| KALKSTANDARD | 1000.050 | -.050 | 94.860 | | .0000 | ALKALI | 1.2040 |
| TONERDEMODUL | 1.845 | 1.795 | 1.845 | | .0000 | HYDR. MODUL | 2.1438 |
| SILIKATMODUL | 2.395 | 2.345 | 2.345 | | .0000 | TONERDEMODUL | 1.8450 |
| C3S | 60.500 | 59.500 | 59.500 | | .0000 | SILIKATMODUL | 2.3450 |
| C2S | 100.000 | -100.000 | 16.642 | | .0000 | KALKSTANDARD | 94.8600 |
| C3A | 100.000 | .000 | 10.287 | | .0000 | SIO2 | 21.4528 |
| C4AF+2C3A | 200.000 | -100.000 | 30.350 | ******************** | | AL2O3 | 5.9327 |
| KOMPON. 1 | 1.000 | .000 | .729 | T O T A L | 1.0000 | FE2O3 | 3.2156 |
| | | | | | | CAO | 65.6038 |
| | | | | | | MGO | 1.3622 |
| OPTIMUM | | | | PREIS | .11111+00 | K2O | .5672 |
| | | | | | | NA2O | .6368 |
| | | | | | | TIO2 | .2507 |
| | | | | | | CR2O3 | .0000 |
| | | | | | | MN2O3 | .1259 |
| | | | | | | SO3 | .1410 |
| | | | | | | P2O5 | .0927 |
| | | | | | | CL | .0538 |
| | | | | | | F | .0000 |
| | | | | | | REST | .57699 |

## 4. PRINCIPLES OF RAW MIX ASSESSMENT

Basically, evaluation and assessment of raw material components (4.4) and raw mixes refer to the same principles. The only difference exists in the immediate comparison of the chemical composition of a raw mix with the standard specifications of the products for which it is intended.

## 4.1 Mix Type

The possible combinations of different rocks used in raw mixes can be classified as mix types. Important varieties are:

- Argillaceous limestone (marl) having the composition of a natural cement. An optimum homogenisation is realised in the rack texture itself. The reactions can easily take place even with a coarsely grained raw mix.
- The same rock in a metamorphic condition contains well crystallised silicates instead of clay minerals. Under otherwise similar conditions, the reactivity is lower than in the first case and there is a high probability that dust formation will occur in the preparation and burning process.
- Contrary to the above cases is the combination of pure limestone with pure clay. To get a close contact between lime and silicate, both components have to be ground finely and homogenised intensively. Depending on the type of clay minerals, the mixes can be more or less reactive,
- A further mix type is the combination of relatively pure limestone, argillaceous limestone and sandstone. Quartz introduced by the sandstone will decrease the grindability and the burnability to some extent. Problems may occur when less reactive minerals are present in the other two components.

Rock combinations actually used can easily be related to this series of mix types. The situation becomes more complicated when additions like pyrite ash, iron ore or bauxite are used.

## 4.2 Comparison of Raw Mix with Standard Specifications

Any raw mix composition has to be compared with the locally applied standard specifications in order to evaluate potential conformity. As an example, Table 48 compares two analyses of typical Portland cements with the ASTM-specifications for the five main types of Portland cement, whereby these types are designated as follows:

| | |
|---|---|
| Type I | Ordinary Portland cement |
| Type II | Moderate sulphate resistance or moderate heat of hydration |
| Type III | High early strength |
| Type IV | Low heat of hydration |
| Type V | High sulphate resistance |

**Table 48 Raw mix composition and specification.**

| | clinker composition | | chemical requirements according to ASTM specifications for type: | | | | |
|---|---|---|---|---|---|---|---|
| | I | II | I | II | III | IV | V |
| Loss on ignition | 0.43 | 0.69 | <3.0 | <3.0 | <3.0 | <2.5 | <3.0 |
| $SiO_2$ | 20.8 | 22.8 | | >21.0 | | | |
| $Al_2O_3$ | 6.0 | 3.8 | | <6.0 | | | |
| $Fe_2O_3$ | 2.5 | 4.4 | | <6.0 | | | |
| CaO | 66.7 | 65.2 | | | | | |
| MgO | 1.4 | 2.2 | <6.0 | <6.0 | <6.0 | <6.0 | <6.0 |
| $So_3$ * | 0.52 | 0.16 | <3.0 <3.5 | <3.0 | <3.5 <4.0 | <2.3 | <2.3 |
| $K_2O$ | 0.80 | 0.39 | | | | | |
| $NA_2O$ | 0.20 | 0.30 | | | | | |
| $Mn_2O_3$ | 0.50 | 0.05 | | | | | |
| $P_2O_5$ | 0.16 | 0.07 | | | | | |
| $TiO_2$ | 0.27 | 0.26 | | | | | |
| Cl | 0.01 | 0.01 | | | | | |
| Total | 99.84 | 100.33 | | | | | |
| Silica ratio | 2.4 | 2.9 | | | | | |
| Alumina ratio | 2.4 | 0.9 | | | | | |
| Lime saturation | 99.6 | 93.4 | | | | | |
| $C_3S$ | 59.9 | 65.1 | | | <35 | | |
| $C_2S$ | 14.4 | 16.2 | | | >40 | | |
| $C_3A$ | 11.7 | 2.8 | | <8 | <15 | <7 | <5 |
| $C_4AF$ | 7.6 | 12.7 | | | | | <20 ** |

* depending on $C_3A$ content ** $C_4AF + 2\ C_3A$

It is obvious in Table 48 that mix I conforms to the specifications for type I (ordinary Portland cement) and type III (high early strength), but not for the other types.

Mix II conforms to all cement types except type IV (low heat of hydration).

If a composition of a potential raw mix does not meet the specifications for a particular type of cement, the following measures have to be weighed:

- Modification of proportioning criteria (lime saturation factor, silica ratio, $C_3A$- or $Al_2O_3$ content, etc.)
- Selection of necessary corrective materials (silica sand, etc.)
- Replacement of components (replacement of an alumina rich claystone by a silica-rich material for production of ASTM type IV and V cements, etc.)
- Replacement of the selected fuel type or fuel quality (coal with little ash instead of coal with a high ash content, if the coal ash composition becomes a critically influencing parameter, etc.)

Influence of minor ("deleterious") elements

The main influencing effect of the so-called deleterious constituents or elements on preparation and production is discussed in chapter 4.4.2. The following deals only with limits and effects of these constituents in the cement raw mix. Under normal circumstances, the following ranges and limits are to be expected:

**Table 49 Deleterious constituents in cement raw mixes**

| deleterious constituents | "normal" range % (clinker basis) | limits % (clinker basis) | remarks |
|---|---|---|---|
| Alkalis:<br>$K_2O$<br>$Na_2O$ | <br>0,5 - 0,8<br>0,2 - 0,4 | <br>0,6<br>as $Na_2O$ | <br>for low-alkali<br>clinker |
| MgO | 1 - 3 | 5 - 6 | according to local specifications |
| $SO_3$ | 0,2 - 1,0 | 1 - 1,5 | higher $SO_3$ in clinker reduces quantity of gypsum to be added |
| $P_2O_5$ | 0,0 .. - 0,3 | 0,5 - 0,8 | |
| Cl | 0,01 - 0,03<br>(0,01 - 0,1) | | depending on and determining the process |
| F | 0,01 - 0,1 | | air pollution |
| $Cr_2O_3$ | 0,01 - 0,04 | | dermatitis |
| $Fe_2O_3$ | 3 - 5 | 0,3 | for white cement production |

These limits should not be regarded as isolated figures but rather as part of a multi-component system (including contributions from the fuel). Particular attention should be given to the systems of:

$K_2O$ ----- $Na_2O$ ----- $SO_3$

$K_2O$ ----- $Na_2O$ ----- Cl

whereby an effort should be made to achieve equalised alkali sulphur balance in order to prevent problems in the kiln system.

Only a few deleterious constituents are limited by specifications, e.g. the MgO and the total alkali-content (for low-alkali clinker). The others are not specified (limited) but practical experience with processing and quality requirements of the product (clinker/cement) dictate their quantitative limits.

## 4.3 Assessment of the Mineralogical Composition of Cement Raw Mixes.

A routinely performed assessment of a raw mix includes as a very important part the examination of the mineralogical composition (Table 50).

**Table 50 Mineralogical assessment of raw mix**

| Minerals | Effects on technology |
|---|---|
| Aragonite ($CaCO_3$) | dry grinding → coating in the mill and high power consumption |
| Quartz ($SiO_2$) | grinding → abrasion, wear and high power consumption<br>burning → impairs burnability |
| Feldspar | burning → impairs burnability, low reactivity |
| Clay minerals:<br>Montmorillonite<br>Illite<br>Kaolinite<br>Chlorite<br>Mica<br>Palygorskite | preparation → water absorption, stickiness<br>burning → improved burnability<br>dust production → reduced dust prod.<br>coating properties → facilitates coating |
| Minerals of good crystallinity | reactivity low, require more energy for transformation |
| Minerals of low crystallinity | reactivity high, less energy necessary for transformation |

## 4.4 Assessment of Raw Mixes with regard to Cement Production and Choice of Process

As discussed previously, the properties of the raw materials, i.e. raw mixes, largely influence the choice of process in general, and the various stages of production. Tables 51 and 52 indicate the most significant relations and functions.

**Table 51 Significance of raw mix properties in cement production. (Compare also Table 51 p. 5/3 referring to raw material properties).**

| Aspects of production | Raw mix properties |
|---|---|
| Quarrying<br>Crushing<br>Transport<br>Storage<br>Grinding | see Table 40 |
| Slurry preparation | clay mineral content, fineness |
| Drying | clay mineral content, porosity |
| Homogenising | chemical and mineralogical variability |
| Nodulising | clay mineral content |
| Dewatering | clay mineral, slurry characteristics(filtration) |
| Burnability | mineralogical composition, fineness, degree of weathering, intergrowth and size of rock fragments |
| Dust formation | mineralogical composition crystallinity |
| Coating formation | chemical composition |

It becomes obvious that the clay mineral content is of paramount importance form many aspects of production.

**Table 52 Summarises the most important raw mix properties influencing the choice of process.**

| Raw mix properties | Related features | WET PROCESS | DRY PROCESS |
|---|---|---|---|
| moisture content | clay mineral content, porosity | high | low |
| plasticity, stickiness | clay mineral content | high | low |
| homogeneity | chemical, physical and mineralogical variability | poor | high |
| chemical characteristics | chemical composition regarding alkalis,. sulphur, chloride, etc. (contents) | high | low |

Table 52 only summarises raw mix aspects. However, other factors, e.g.

- seasonal fluctuations of moisture content
- transport, haulage etc.

are, of course, also determining factors in the choice of process.

## 4.5 Evaluation of Laboratory Test Results

The steps which are regarded as the final part of a mix design, are preparation, examination and evaluation of test results produced in a laboratory.

### 4.5.1 Preparation

The proper preparation of laboratory raw mixes for testing is the prerequisite for reliable test results and subsequent evaluation.

It is as important as sampling and it should, therefore, be emphasised that both these processes have to be carried out under observation of strictly defined rules and controls.

### 4.5.2 Significance of Laboratory Investigations

The characteristics and behaviour of a cement raw material or mix during the various stages of production can never be predicted on the basis of the test results and findings of laboratory investigations alone. Laboratory testing has the disadvantage that many influencing and technologically important parameters such as kiln atmosphere, industrial preparation, etc., can be neither simulated nor reproduced on a laboratory scale. Laboratory produced test results, however, permit the recognition and interpretation of tendencies, whereby a broad variety of individual findings assures a more reliable final evaluation. It is thus recommendable to conduct a series of tests, the results of which can be used to support and control each individual finding. For instance, when the filtration properties of a cement slurry have to be assessed, mineralogical/chemical investigations grain size distribution tests, rheological tests on slurry and specific filtration tests should be conducted rather than a specific filtration test only. The same idea is applicable for all the other assessments of technological properties such as burnability characteristics, grindability properties, etc.

In order to guarantee that the laboratory results correspond as closely as possible to the findings of industrial practice, the design of the laboratory testing methods and other aspects such as limits, reproducibility, etc. should periodically be checked and compared.

### 4.5.3 Summary of Laboratory Tests

The following tests are available and normally applied in the cement industry (Table 53).

**Table 53 Laboratory tests**

| Material aspects | Test designation | Limits, reproducibility, practice relevance |
|---|---|---|
| Stickiness | soil tests | |
| Burnability | burnability test | tendencies only, but good practice relevance |
| Grindability | grindability test | quantitative estimate of kWh/t requirements |
| Volatility of circulating elements | volatility test | quantitative estimate of primary volatility in various atmospheres |
| Coating behaviour brick selection | coating test | tendencies only, acceptable practice relevance |
| Filterability | filtration test, testing of slurry rheology | quantitative estimate of key-factors quantitative assessment of rheology |
| Nodulisability | granulation test, thermo-shock test strength test | tendencies only, practice relevance acceptable |

Normally these technological tests are supported by:

- chemical analysis (highly accurate)
- mineralogical analysis (semi-quantitative)
- grain-size analysis (accurate)